

Capturing Waveforms in a

HOW will scientists “see” what happens inside the National Ignition Facility (NIF), the world’s largest laser, when it creates the extreme temperature and pressure conditions found in stars? Instruments such as oscilloscopes and streak cameras cannot capture all the details of fast-moving, complex events such as fusion burn. Their dynamic range (the ratio between the smallest and largest possible values) and their temporal resolution (the precision of a measurement with respect to time) are coupled. As a result, these conventional instruments lose dynamic range with faster temporal resolution or lose temporal resolution with more dynamic range.

To meet the emerging need for greater dynamic range and temporal resolution, scientists can turn to the new FemtoScope—a “time microscope” that is attached to the front end of a conventional recording instrument to dramatically improve its performance. Livermore researchers, in collaboration with colleagues from Stanford University, the University of Southampton, and the University of California at Davis, won an R&D 100 Award for their invention of the FemtoScope. Initial efforts for this work were funded by Livermore’s Laboratory Directed Research and Development Program.

Slowing Down the Signal

The FemtoScope improves the performance of an oscilloscope or streak camera much in the same way that a high-performance lens improves a camera’s output. (See *S&TR*, June 2007, pp. 4–10.) It is not a recording instrument in itself. Rather, it dramatically enhances the performance of any conventional

recording instrument to which it is connected by ultrafast processing of waveforms. The FemtoScope improves the dynamic range of these instruments and their time resolution from tens of picoseconds (trillionths of a second) to hundreds of femtoseconds (quadrillionths of a second).

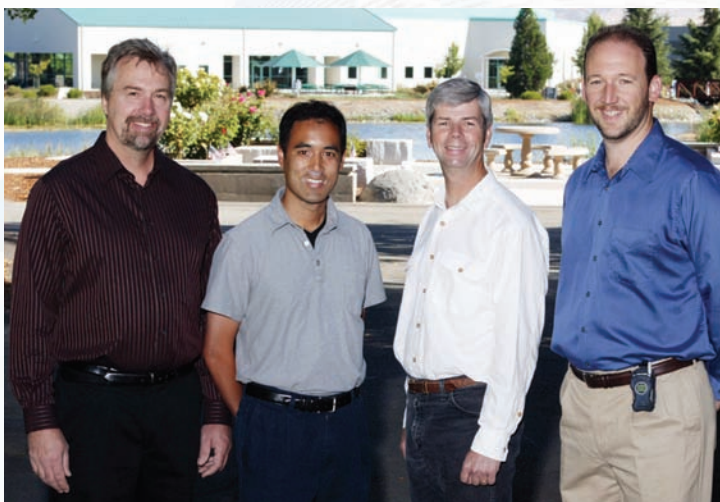
“The temporal imaging technology on which the FemtoScope is based is fundamentally a time-scale transformation tool that can be configured to magnify, compress, reverse, and even Fourier-transform ultrafast waveforms,” says Livermore scientist Corey Bennett. “We have concentrated our efforts on developing a time-magnification system.” Just as a scanning electron microscope’s powers of magnification can reveal nanometer-size details of an object’s structure not viewable with an ordinary light microscope, so the FemtoScope’s powers of time magnification can reveal the peaks and valleys in a 1-picosecond signal not detectable by a standalone oscilloscope or streak camera.

In the past, other instruments have obtained very high resolution by conducting repetitive waveform sampling and averaging with ultrashort time intervals. However, because NIF will be fired a maximum of four times a day, diagnostics must operate in a single-shot mode, and repetitive sampling approaches are not an option.

By slowing down or “magnifying” the time scale of the signal before it enters the recording instrument, the FemtoScope allows the capture of signals that otherwise would be too fast to record in any detail. This process not only improves the resolution of the recording system but also increases the available dynamic range at a given speed. In the figure on p. 7, a simulation shows how three optical pulses separated by 6 picoseconds (first to last) can be “time magnified” so that they occur over 18 picoseconds at the output.

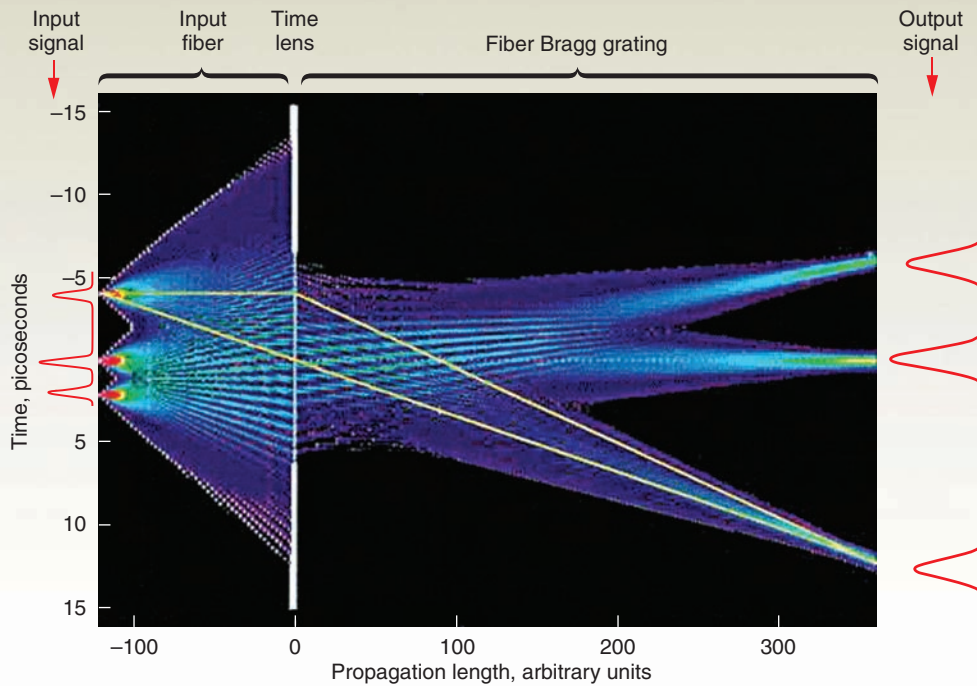
The FemtoScope uses a single-shot process in real time to capture each window of time (or frame) of interest and stretches out the waveform so that greater detail is revealed. Furthermore, this process can be repeated at a rate of more than 100 million frames per second to record the real-time evolution of a signal. With ultrafast resolution and nearly endless recording length, this instrument can uncover waveform data with peaks and valleys never before detectable.

When combined with an oscilloscope, the FemtoScope produces an instrument capable of recording 100-picosecond frames at 155 million frames per second until its memory is full. When



Livermore development team for the FemtoScope (from left): Bryan Moran, Vincent Hernandez, Alex Drobshoff, and Corey Bennett.

Quadrillionth of a Second



A false-color image shows three pulses propagating through a temporal imaging system with a magnification of three times. Color here represents intensity or brightness, with red being the brightest. The simulation shows how three optical pulses occurring in a 6-picosecond time frame can be "time magnified" so that, at the output, they occur over 18 picoseconds.

combined with an optical streak camera, the FemtoScope produces an instrument with a 20-times increase in temporal resolution and a 30-times increase in dynamic range, resulting in an overall improvement of 600 times compared with the performance of the streak camera alone.

Emerging Needs

The FemtoScope represents a fundamental paradigm shift in high-speed imaging technology. As researchers improve their understanding of physical phenomena, they will need to examine processes on shorter and shorter time scales. The FemtoScope will be an invaluable tool for collecting detailed dynamic data at faster temporal resolution.

The Laboratory plans to use the FemtoScope on NIF experiments, which will need diagnostics with time resolutions on the scale of 1 picosecond or less to determine when high-energy photons first appear and what happens from their first appearance to their peak production. The FemtoScope will also be useful for detecting and recording a broad range of signal strengths—from very weak signal intensities to very strong.

The true potential of temporal imaging is just beginning to be explored. The FemtoScope could also be applied to several

other high-energy-density-physics and fusion-energy research facilities and experiments with diagnostic needs similar to NIF's. The Defense Advanced Research Projects Agency is cofunding Livermore to develop the technology for lidar (light detection and ranging), which measures the properties of scattered light to gather information about a distant target.

The FemtoScope will also be a valuable tool for Livermore researchers who are beginning development of a new energy concept known as Laser Inertial Fusion Engine, or LIFE, which is based on physics and technology developed for NIF. (See *S&TR*, April/May 2009, pp. 6–15.) LIFE has the potential to meet future worldwide energy needs in an inherently safe, sustainable manner without carbon dioxide emissions, while dramatically shrinking the planet's stockpile of spent nuclear fuel.

—Karen Rath

Key Words: dynamic range, FemtoScope, R&D 100 Award, temporal imaging, temporal resolution, time microscope.

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